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The magnetic induction heating of graphene coated iron coated iron composite

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A graphene -coated iron nanoparticles produced by carbon arc method, which can be used as a new kind of magnetic targeting and heating drug carrier for cancer therapy. It presents an special nanostructure of iron nanoparticles in inner core and nano-graphene shells outside. The inner core has great effect of targeting magnetic heating and its nano-graphene shells have a high drug adsorption ability due to its high surface area. Magnetic induction heating effect of pig liver injected mixed liquids with different concentration graphene coated iron particles in physiological saline indicates that the more quantity of nanoparticles used, the higher temperature it is. Magnetic induction heating effect of the pig liver was compared in the case of filling method and injection method (both were containing 0.3g graphene coated iron nanoparticles). The iron nanoparticle in its inner core has good effect of magnetic induction heating, the temperature can go up to 51 ℃ in the case that graphene coated iron nanoparticles mixed with physiological saline were distributed uniformly in pig liver. And the temperature can go up to 46℃ in the case that graphene-coated iron nanoparticles was injected in a certain section of pig liver. It is obvious that injected one is much better than that of filled, but they are all enough to kill the cancer cells.

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1. Introduction

Technical advances have enabled the preparation of anticancer particles with greater specificity and fewer side effects [1]. Tumors have aberration of tumor blood and lymphatic vasculature, which provides access to circulating particles [2,3]. For specific targeting efficiency, studies have phenomenally selective targeting of designed nanostructures to tumor within this size range (10-100 nm) accumulate within solid tumors owing to the enhanced permeability and retention effect (EPR effect) [4,5]. The effect began a development of nanometer sized carriers to more efficiently deliver therapeutic and/or diagnostic agents。At the same time various types of

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hyperthermia therapy such as radio frequency, infrared, microwave, focused ultrasound or magnetic[6-9]. Recently, a lot of effort has been put into combining more than one mode of heating into one treatment. Although the chemotherapy is a first-line therapeutic approach for the treatment of cancer, it may damage healthy tissues, leading to irreversible aide effects.

Goal's research shows that normal cells and cancer cells are very different in high temperature[10], cancer cells are sensitive to temperature and will be killed in 42℃, while normal cells is still alive in 45℃. Therefore, when temperature of the tumor is over 42℃, the tumor cells may be destroied.. so confine heating in the cancer lesion area, and accurately control the heating temperature is crucial for cancer therapy[11,12]. Graphene capsuled magnetic nanoparticles are one new type magnetic material, it present an especial core-shell structure, that is metals nanoparticle is in inner core and graphene shell is outside. The properties of graphene-capsuled magnetic nanoparticles may be different from those of the corresponding magnetic nanoparticles. graphene-coating can provide a protective layer surrounding a magnetic core in order to enhance the resistance of core materials to oxidation.

In the present work，we prepared core-shell Fe-graphene composite nanoparticles by carbon arc method. Core-shell Fe- graphene composite nanoparticles, which have special nanostructure-graphene shell wrapping iron structure. These graphene shells protect iron core from being oxidized. The graphene shells are porous, which makes graphene shells have favorable radio frequency wave pierce property, iron cores have high magnetically targeting ability and electromagnetic wave absorption ability, on account of being wrapped by graphene shells, the iron particles are able to anti-oxidate. So graphene coated iron particles are more stable than iron particles. This study provides new insights into the magnetic induction heating performance. this new kind of nanomaterial.

2. Experiment

Graphene capsuled iron particles were prepared by carbon arc method. In brief, cathode was pure graphite rod, while anode was mixture powder of different proportion Fe powder and graphite powder; High purity argon was protection air, pressure was 50 kPa; discharge current was 150A, voltage was 22V, after reaction, products on the combustion chamber wall were collected by a brush and consequently washed by methyl benzene. The remainder was graphene coated iron particles.

XRD and TEM were used to investigate pattern and structure of graphene coated iron particles. Magnetic induction heating effect was tested by high frequency alternating magnetic power source, the testing current of this power source was 300-600A. When graphene coated iron particles were put into the magnetic induction area, these particles will be heated by magnetic induction field. In this experiment graphene coated iron particles were put into pig liver, and put the pig liver into high frequency alternating magnetic field. Then temperature change was recorded 5 minutes interval.

3. Results and discussion

3.1. Pattern and structure of graphene coated iron nanoparticles

Arc discharging is a drastic reaction, which produces very high temperature (about 3000K) in discharge area [8], at this temperature the discharge material will be decompose into free atom, positive ion and electron. When they depart from the high temperature discharge area, the temperature decreases drastically, these particles will combine to form core-shell structure nanoparticles. The shells are graphene amorphous and the cores are Fe crystal. Fig.1 is XRD patterns of different content iron graphene encapsulating iron nanoparticles, (iron content in the sample are 20%, 40%, 60%, 80% respectively), it confirmed the presence of face-centered cubic (fcc) crystalline iron metal, at 2θ ≈ 44°, 51°, 74°,and with the increase of iron content it's diffraction peak increase. 2θ ≈25°, 43°, 65° corresponding to the diffraction peak of graphene. What can be seen from the diagram, the products only have carbon and iron peaks do not find iron carbide and oxide diffraction peaks, indicating graphene encapsulating iron nanoparticles did not contain iron oxides and carbides.

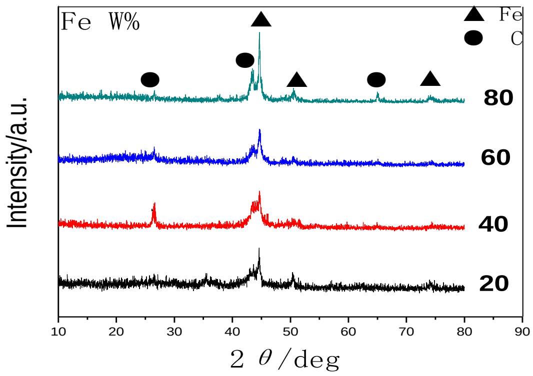
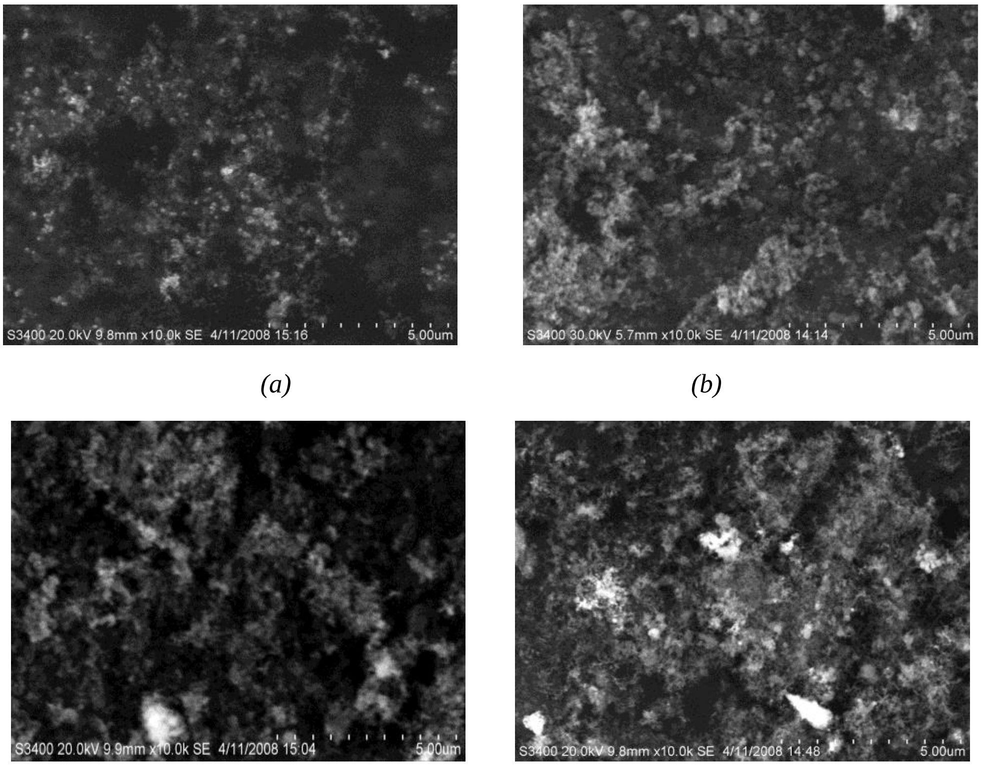


Fig 1. XRD patterns of different content iron graphene encapsulating iron nanoparticles.

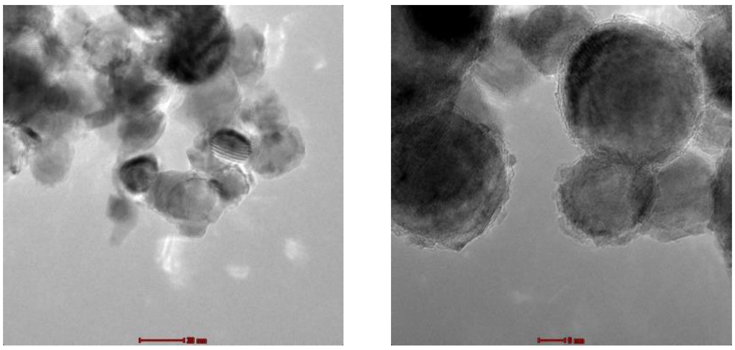
Fig. 2 is the SEM analysis indicated that the composite are spheres with particle size of approximately 20-50nm. It is observed that the particles aggregated on the surface and it's getting serious with increase of iron content. Fig. 3 shows TEM image of the composite, it conform the SEM image that the particles are spheres. The graphene encapsulating iron nanocomposites blend with carbon particles, obviously the composites are core-shell structure, the Fe core are about 15nm and the graphene layer 3-4nm in thickness.



(a) *(b)*

(c) *(d)*

Fig. 2. SEM images of nanoparticles with different iron content(a:20%; b:40; c:60; d:80).



(a) *(b)*

Fig. 3. TEM image of the nanoparticles with different iron content(a:20%; b:80%).

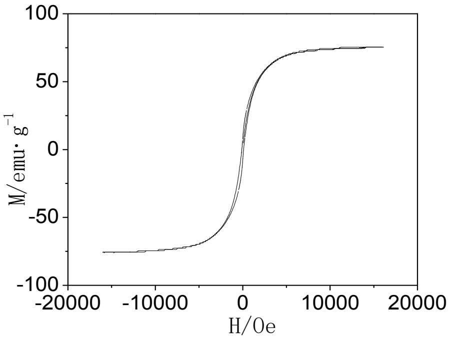


Fig. 4. Hysteresis loops at room temperature of graphene encapsulating iron nanoparticles.

The Fe core of particles possess magnetism property, The hysteresis loops at room temperature of graphene encapsulating iron nanoparticles (Fig.4) show that the samples are saturation magnetization materials. The saturation magnetization is 75.46 emu/g, remanent magnetization is 8.48emu/g, intrinsic coercive force is 95 Oe.

3.2. Effect of Pig liver magnetic induction heating after being injected suspension of physiological saline and graphene coated iron nanoparticles

0.3g and 0.15g graphene coated iron nanoparticles(Fe containing is 40%)were dispersed into 2ml physiological saline respectively, then inject the suspension into pig liver. Fig.3 shows the relationship between time and temperature. And Fig.5 are the pig liver magnetic induction heating effect curves after being injected 0.075g/ml nanoparticles suspension, the particles are different in Fe containing (Fe containing is 40%,50% and 80% respectively).

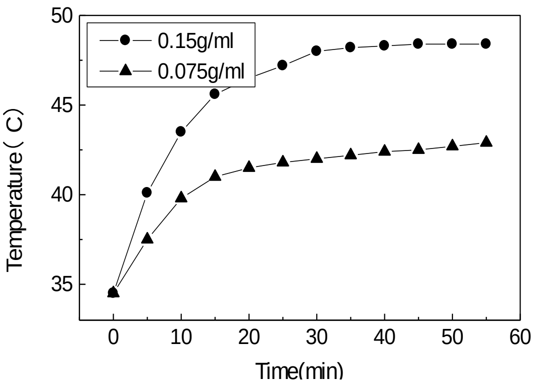


Fig. 5. Magnetic induction heating curves of pig liver injected different concentration graphene coated iron nanoparticles of physiological saline suspension.

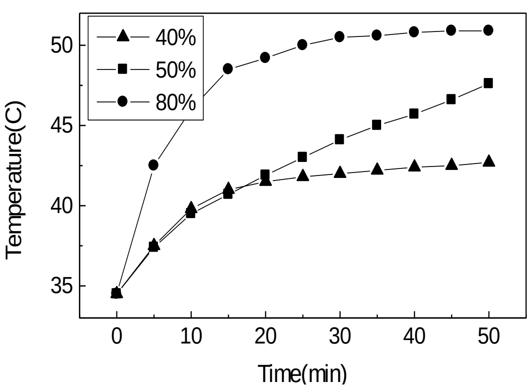


Fig. 6. Magnetic induction heating curves of pig liver injected 0.075g/ml graphene coated iron nanoparticles with different Fe containing and physiological saline suspension.

Fig. 6 shows magnetic induction heating effect of pig liver, which was injected different concentration of 40% Fe graphene coated iron particles and physiological saline suspension. From the curves we can draw a conclusion that the higher particle concentration was, the faster the pig liver temperature increases. By contrast, we put pure physiological saline into alternating magnetic field, it has no induction heating effect. Fig .4 is pig liver magnetic induction heating effect curve, which was injected into different Fe containing graphene coated iron particles suspension (concentration 0.075g/ml). In the initiation stage ,the 40% and 50% Fe particles suspension have the same temperature increase rate, after 20 min the one of 40% Fe (by content) almost doesn't increase and comes into temperature stable stage. While the 50% Fe containing suspension temperature increases continually in all the stage. It is obvious that the more Fe containing was, the higher that the suspension temperature increases. After 30 minutes magnetic induction heating ,the one 40% Fe containing reaches 42℃, 50% Fe containing reaches 44℃ and 80% Fe containing reaches 51℃. At 42 ℃ the tumor cells will be destructed, the graphene coated iron particles magnetic induction heating temperature can reach more than 50 ℃,this temperature is enough to kill tumor.

3.3. Different position of pig liver megnetic induction heating effect after being injected suspension of physiological saline and graphene coated iron nanoparticles

Suspension of 0.075g/ml 40% Fe containing graphene coated iron nanoparticles and physiological saline and 0.15g/ml 40% Fe containing graphene coated iron nanoparticles and physiological saline was injected into pig liver respectively. Then test different part temperature of the pig liver. Fig .7 is 0.075g/ml one and Fig .8 is 0.15g/ml one. As it was illustrated in the graph that the temperature changes in different part of the pig liver. The reason was that when suspension was injected into pig liver, The particles concentrate in the middle of the organ. they are confined in the injection area by the magnetic field . So the temperature was higher in the middle of liver than that of surface area. 0.15g/ml suspension can heat the middle of the liver to 48℃, while the surface was only 33℃. Therefore, the magnetic field doesn't affect the part of the organ without graphene coated iron particles, so this nanomaterial was capable of killing tumor cells meanwhile the normal cells can avoid being hurt.

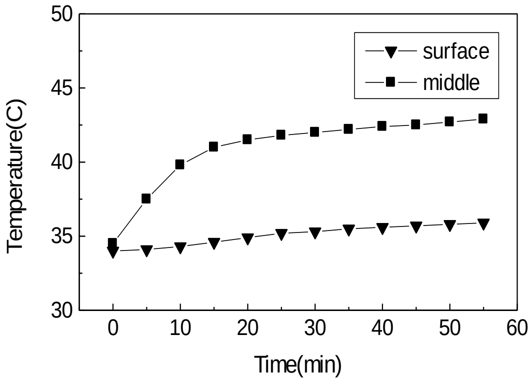


Fig. 7. Different position magnetic induction heating effect of pig liver after being injected 0.075g/ml 40% Fe containing suspension.

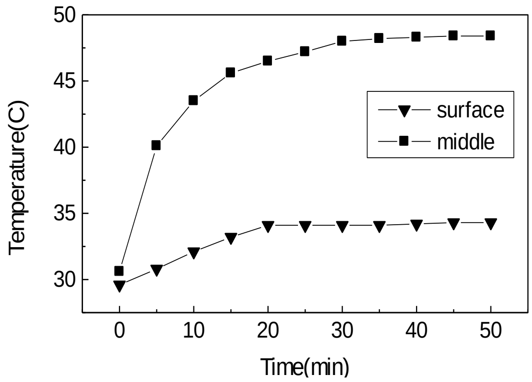


Fig. 8. Different position magnetic induction heating effect of pig liver after being injected 0.15g/ml 40% Fe containing suspension.

4. Conclusion

Graphene encapsulating iron nanoparticles were prepared arc method, they are core-shell structure and the iron nanoparticles are fully wrapped by nano graphene layers with a diameter of 20-40nm;

In the focusing alternating magnetic field, the graphene coated iron nanoparticles can be as both induction heating source and magnetic target delivery to tumor therapy, the influencing factors of induction heating effect as follows: (1) quantity of drug carrier: the more graphene coated iron nanoparticles being used, the higher temperature it was. (2) quantity of magnetism materials in particles, high containing of Fe particles have better heating effect than the one of low Fe containing. (3) time of induction heating, the temperature will increase with the extension of induction heating time, finally it will reach a stable temperature stage.

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